FIELD INTERCOMPARISON OF TWO CURRENT METERS IN AN UNDER-ICE ENVIRONMENT UNDER CONDITIONS OF LOW CURRENT SPEEDS

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ABSTRACT

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Data from two current meters moored in an under-ice environment were compared to estimate their response in the absence of wind-induced current meter motion. The instruments were an Aanderaa RCM4S and an Applied Microsystems VACM-12. Results show that the RCM4S overread the VACM by about 1 cm s^{-1} over the entire speed range encountered (0-15 cm s^{-1}). A large mean direction difference (20°) was also noted between the two instruments. The source of this problem may be that the mooring anchor was too close to the instruments. Finally, the VACM direction sensor showed a tendency to stall and give the same reading over many consecutive samples while the RCM4S direction was changing. No explanation has been found for this behavior.

RÉSUMÉ

Larouche, P. 2000. Field intercomparison of two current meters in an under-ice environment under conditions of low current speeds. Can. Tech. Rep. Hydrogr. Ocean Sci. 210: v + 12 p.

Des données provenant de deux courantomètres installés sous une couverture de glace ont été comparées afin d'estimer leur réponse en l'absence de mouvements des instruments induits par le vent. Les instruments étaient un Aanderaa RCM4S et un Applied Microsystems VACM-12. Les résultats montrent que le RCM4S a mesuré des vitesses d'environ 1 cm s^{-1} supérieures à celles du VACM sur l'ensemble de la gamme de vitesses mesurées (0-15 cm s^{-1}). Une grande différence de direction moyenne (20°) a aussi été notée entre les deux instruments. La source de ce problème est peut-être reliée à la trop grande proximité entre l'ancre du mouillage et les instruments. Finalement, le capteur de direction du VACM a montré une tendance à indiquer la même valeur durant plusieurs mesures consécutives pendant que celle du RCM4S variait. Aucune explication n'a pu être avancée pour expliquer ce phénomène.

1.0 INTRODUCTION

To measure currents, oceanographers can choose between instruments that use very different techniques including rotors and vanes, electromagnetic induction, acoustic travel time, and Doppler instruments. Faced with a particular situation, the oceanographer wants to know which instrument will provide the best data and how data from different instruments compare. Many previous experiments that compared instruments have shown large discrepancies between oceanic and laboratory measurements. However, due to the large number of different current meters available, not all instruments were included in these intercomparison programs. One of these is the Applied Microsystems VACM-12. This instrument is particularly well adapted for moorings through the ice because of its small diameter. Its fast response vane improves on the long response time of large vanes, which leads to an overestimation in weak currents (Saunders, 1980; Larouche and Deguise, 1989; Woodward *et al.*, 1990). During a project done in an ice-covered area where low current speeds exist, we had the opportunity to do a field test to evaluate the efficiency of this instrument. The experiment was also supposed to include tests of an Inter Ocean S4 and a Neil Brown SACM. However, these two current meters did not work properly, preventing their inclusion in this study. This paper reports on the intercomparison of the VACM-12 with a current meter that has been thoroughly evaluated under many environmental conditions, the Aanderaa RCM4S (Saunders, 1976; Pearson *et al.*, 1981; Beardsley *et al.*, 1981; Sherwin, 1988; Larouche and Deguise, 1989; Woodward *et al.*, 1990).

2.0 THE INSTRUMENTS

The two instruments evaluated, the RCM4S and VACM-12, have different current-measuring devices. The RCM4S uses a paddle wheel rotor to measure mean current speed during a given period with a stated accuracy of 1 cm s^{-1} (Aanderaa, 1983). Direction is measured at the end of the period by reading an instantaneous value from the magnetic compass; the instrument is aligned with the current with a large vane. Compass accuracy is 7.5° for current speeds of less than 5 cm s^{-1} and 5° above that limit (Aanderaa, 1983).

The VACM-12 is a vector-averaging instrument that measures current speed using a modified Savonius rotor with an accuracy of 2% of the reading (Applied Microsystems Limited, 1988). A small, neutrally buoyant, fast-response vane imbedded in the instrument frame provides current direction relative to the housing, and a digital compass gives the housing orientation. The combined resolution of these two devices is 2.8° (Applied Microsystems Limited, 1988). In the vector-averaging sampling mode, the current direction is measured every quarter of a turn of the rotor, yielding a displacement vector. This vector is decomposed into its north and east components that are then summed in memory and averaged over the selected time interval. Mean components are then used to calculate the magnitude and orientation of the current vector.

3.0 THE EXPERIMENT

The experiment took place in southeastern Hudson Bay, in the winter of 1988 (Figure 1). This location was selected because its stable ice cover (Larouche and Galbraith, 1989) provides a good environment to test current meters. The complete fast ice cover precludes wind-induced surface waves that can contaminate the data and allows the installation of the instruments close to each other at precise depths. The site was located close to the municipality of Kuujjuarapik, which is easily accessible by daily flights by a major airline. Transportation to the ice was by snowmobiles.

The selected test site was located 15 km offshore of Kuujjuarapik, where a field camp was established away from the possible influence of the Great Whale river plume (Ingram and Larouche, 1987). The water depth at this location was 100 m. Knowledge of the circulation in this portion of Hudson Bay is relatively scarce. Measurements done during winter 1986 showed that the under-ice circulation pattern is complex and variable, with current speed increasing away from the under-ice surface (Pettigrew and Larouche, 1992). Tide is the main driving force for the currents over short time intervals (24 hours). The two instruments were suspended 15 m apart, both at a depth of 30 m from the under-ice surface (Figure 2). Tidal currents at this depth are approximately 15 cm s^{-1} (Pettigrew and Larouche, 1992). Mooring location was in the middle of a big floe (~1 km^2) with a relatively smooth under-ice surface as verified by divers. The RCM4S averaged the current speed over 5 minute periods and then took instantaneous direction at the end of the period. The VACM averaged the current over 4.5 of the 5 minutes period due to its internal sampling strategy.

Upon recovery, the tapes containing the data were decoded and spikes were removed. The length of both series was 7394 data points (25.7 days). The formulas used to transform the raw data into engineering units are presented in Appendix 1. Initial examination of the data showed that both instruments seemed to have worked well and returned good data. However, upon further analysis, some problems were found with the VACM data set. The first is related to the current direction calculated when the current speed is lower than the stall speed of the rotor. When the rotor does not move over a sampling interval, there is no current direction sampled and no vectors calculated, leading to a value of zero being recorded on the tape for both the speed and direction components even if the vane actually moved. This is a good approach for the speed measurement, as the current intensity was very small, but it leads to a problem when analyzing current direction measurement performance with an over-representation of zero values for this variable. The 640 data points containing both VACM current speed and direction values of zero were thus eliminated from the comparison of direction measurement performance. This problem cannot occur in the RCM4S because there is always a direction reading at the end of the recording period whatever the current speed was. Examination of the RCM4S data file showed that the current direction did change when the rotor count was null.

Another problem was found with the VACM direction measurement. It appears that the raw values of 64 and 192 were never recorded by the instrument leading to two coherent gaps at 81° and 261° in the data file. The fact that the two values are separated by an exact power of 2 (128) pinpoints a problem with the instrument electronics. However, this error does not have any visible effect on the instrument intercomparison.

Finally, it was also noted that the VACM vane appeared to stick at times, having the effect of artificially increasing the direction difference between the two instruments. To investigate this situation, the VACM data file was checked for occurrences of the same direction appearing consecutively more than three times. We found a total of 144 such events having a mean duration of 7.2 samples. Adjacent events with digital counts not changing by more than 1 were considered as a single event. The longest event was 48 samples (4 hours) long. In comparison, only one such event was found in the RCM4S data. Looking at these events, we noticed that they were roughly divided into two broad categories (Figure 3). The first included short duration–high speed events while the other included long duration–low speed events. The separation between the two types of events is roughly 5 cm s^{-1}. There were 66 events in the first category, having a mean duration of 5.2 samples, and 78 events of the second category, with a mean duration of 9.0 samples. Comparing these events with data taken simultaneously by the RCM4S, we found that almost all the high speed events occurred at times of very steady tidal currents and thus appeared to be true data. We thus filtered the data file using the following methodology: events for which the simultaneous RCM4S data showed that the current direction did not changed by more than 5° (the best RCM4S precision) were considered good data and kept in the comparison. This procedure led to the elimination of 74% of the low speed events but only 24 % of the high speed ones for a total of 661 data points.

The cause of this problem is hard to pinpoint. The time distribution of the eliminated events (Figure 4) shows two concentrations. The first occurred on April 25-26 and the second towards

the end of the experiment (May 6). These two dates correspond to periods of neap tides, indicating that the VACM vane may not be responding as designed under low current speed conditions. No biological fouling was noticed when the instrument was recovered, which is normal in an under-ice environment where most of the algal production occurs at the ice water interface. Also, no signs of wear were seen on the vane assembly, eliminating this type of mechanical problem from consideration. Further experiments will be needed to determine exactly what went wrong with the VACM direction sensor.

In summary, the combined VACM particularities (zero direction) and errors (stuck rotor) led to the elimination of 1301 direction points, representing 18% of all recovered data, from the comparison. Therefore, subsequent direction analysis was made using 6093 simultaneous samples from both instruments. Speed comparisons were made using the entire data set of 7394 samples.

4.0 RESULTS AND DISCUSSION

4.1 SPEED MEASUREMENTS

The plot of VACM-12 speed versus RCM4S speed (Figure 5a) shows that, except at very low speeds, the VACM consistently measured lower speeds than the RCM4S. Table 1 shows the mean of the absolute speed difference (RCM4S - VACM) between the two instruments for different speed ranges. The mean absolute difference was used to prevent errors of opposite signs from canceling each other in the calculations and thus artificially creating better statistics. For every speed range, the average speed difference was always less than the stated instrument accuracy, with a mean difference over the whole speed range of 1.0 cm s^{-1}.

The linear regression analysis of the two speed series showed both speeds to be highly correlated ($r = 0.966$). The regression line is:

$$RCM4S = 1.342 + 0.9232\ VACM \qquad (1)$$

These results are only slightly different from those of previous intercomparisons. It has already been noted that the Aanderaa current meter overreads other instruments even when fitted with a paddle wheel rotor (Halpern *et al.*, 1974; Saunders, 1980; Beardsley *et al.*, 1981; Hammond *et al.*, 1986; Larouche and Galbraith, 1989; Woodward *et al.*, 1990). However, overreading was previously found to increase with the current speed, which does not appear to be the case in this experiment. In the other comparisons, overreading was associated with wave action and mooring motion (Hammond *et al.*, 1986; Woodward *et al.*, 1990) or possibly with a different calibration of the instruments (Larouche and Deguise, 1989).

Previous studies have suggested that the Aanderaa RCM4S underreads other current meters at low current speeds (< 5 cm s^{-1}) (Larouche and Deguise, 1989; Woodward *et al.*, 1990). This results from a shielding of the rotor by improper alignment of the vane with the current. Only a handful of such errors seemed to occur in the present experiment for speeds under 3 cm s^{-1}, as shown in Figure 5a. On the other hand, the results show that the VACM may be used in these low speed environments when the vane is functioning correctly, since it has the same type of comparative response to the RCM4S as current meters like the Inter Ocean S4 or Neil Brown Smart Acoustic Current Meter (SACM) (Larouche and Deguise, 1989). This probably results from the combination of an unshielded rotor and the use of a small, fast response vane that can follow varying currents of small amplitude. Further comparisons of the VACM should be done with current meters having no moving parts (e.g., S4 or SACM) to confirm this ability to measure very small currents and perhaps shed more light on the stuck rotor problem encountered in this experiment.

Table 1. Mean absolute differences of the speed and direction over various speed ranges.

RANGE (cm s^{-1})	NUMBER OF DATA POINTS		MEAN DIFFERENCE		STANDARD ERROR	
	SPEED	DIRECTION	SPEED (cm s^{-1})	DIRECTION (Deg.)	SPEED (cm s^{-1})	DIRECTION (Deg.)
0-2	1137	436	1.16	34.63	0.71	33.77
2-4	855	634	0.86	26.72	0.47	25.97
4-6	2104	1847	1.14	22.67	0.50	17.38
6-8	1957	1850	1.03	22.76	0.66	14.88
8-10	924	903	0.85	22.15	0.70	14.90
> 10	417	423	0.59	22.57	0.58	22.79
All data	7394	6093	1.02	24.24	0.63	19.76
> 5	4326	4127	0.99	22.73	0.66	15.60

4.2 DIRECTION MEASUREMENTS

A systematic direction difference can be seen between the two instruments (Figure 5b), with the RCM4S recording a current direction anticlockwise to that of the VACM direction. Mean absolute direction difference was 23° over the record length (Table 1) with a larger error (35°) occuring at very low speeds (<2 cm s^{-1}). This can probably be related to the misalignment of the RCM4S vane under conditions of low amplitude current, which increases the error in the direction estimate (Saunders, 1980; Larouche and Deguise, 1989; Woodward *et al.*, 1990). Above 5 cm s^{-1}, the mean difference was reduced to 23° with a standard deviation of 15.6°. This value is nevertheless much higher than the combined precision of both instruments and must be explained.

Two main sources of error can affect the measurement of direction: internal or external to the instrument. The RCM4S has been particularly well tested for the presence of internal sources of errors (Keenan, 1979a, 1979b). Without going into detail, three main sources of errors may falsify the measured instrument direction: the magnetic fields generated by the encoder magnet, the rotor and follower magnets, or the magnetization of the tape recording the data. In an ambient earth horizontal magnetic field of 11,000 gammas, the first two error sources can both reach about 7° peak to peak, while the third is dependent on the amount of magnetization of the tape and can be evaluated at about 5° for a new tape. No such figures exist for the VACM, but for a first approximation, we can probably estimate these errors to be of the same order of magnitude. These error sources could thus easily explain most of the observed 24° difference if they were all in phase and added up. However, we do not believe these internal sources to be the main factor explaining the mean 24° error between the two instruments. Since the instruments were calibrated prior to the experiment, the internal sources of errors should already have been taken into account with the exception of the tape magnetic field. Thus there only remains one explanation for the systematic difference: a magnetic disturbance external to the instruments. After reviewing our mooring practices, we found that the weights used to keep the moorings vertical were made of

steel and were located within 30 cm of the instrument's compass. Recent laboratory tests have shown that even the relatively small iron weights used (40 kg) can deviate the magnet by as much as 15° when located this close to the compass (R. Bélanger, personal communication). It is thus probable that both instruments were affected by this disturbance, which resulted in the observed 20° discrepancy. We also believe this to be the cause of the systematic direction difference found in a previous comparison that used the same mooring technique (Larouche and Deguise, 1989). To eliminate such problems in the future, we recommend either the use of non-magnetic weights or, if impractical, that the weights be placed far away (5 m) from the instruments.

5.0 CONCLUSION

The results of this intercomparison show that the Applied Microsystems VACM-12 and the Aanderaa RCM4S had equivalent overall performance in an ice-covered environment with current speeds of 5 to 15 cm s^{-1}. The RCM4S slightly overread the VACM by about 1 cm s^{-1}. The VACM seemed able to measure currents less than 5 cm s^{-1} better than the RCM4S. However, this capacity should be further evaluated by comparison with current meters designed to measure very small speeds before being used in weak currents. The biggest advantage of the VACM over the Aanderaa for under-ice moorings is its small diameter, which greatly facilitates deployment. However, the VACM had numerous mechanical and/or electronic problems that should be corrected prior to its use on a regular basis.

The Hudson Bay test site was ideal for evaluating the comparative performance of current meters of different designs under conditions free from surface wave pumping. The major drawback with this location is the absence of currents stronger than 15 cm s^{-1}, which limits the usefulness of the experiment. To test the performance of the instruments in stronger currents, it would be necessary to move to another location. Such locations exist further north (e.g., Lancaster Sound), but environmental conditions (thicker ice) and reduced accessibility would increase the difficulty of setting up the experiment. As most instrument problems occur at very low speeds, we think that the Hudson Bay site is still a good location for *in situ* current meter tests. With the constant evolution of sensors, it would now be possible to do a new round of tests comparing four different technologies (mechanical, acoustic, magnetic field, and Doppler).

ACKNOWLEDGEMENTS

I would like to acknowledge the work of Daniel Lachance, who participated in the instrument mooring, and George Heckman, who worked on data analysis. The VACM-12 was graciously provided by the Hydrographic Service of Canada. This work also benefited from the pertinent comments of Peter Galbraith and Denis Gilbert.

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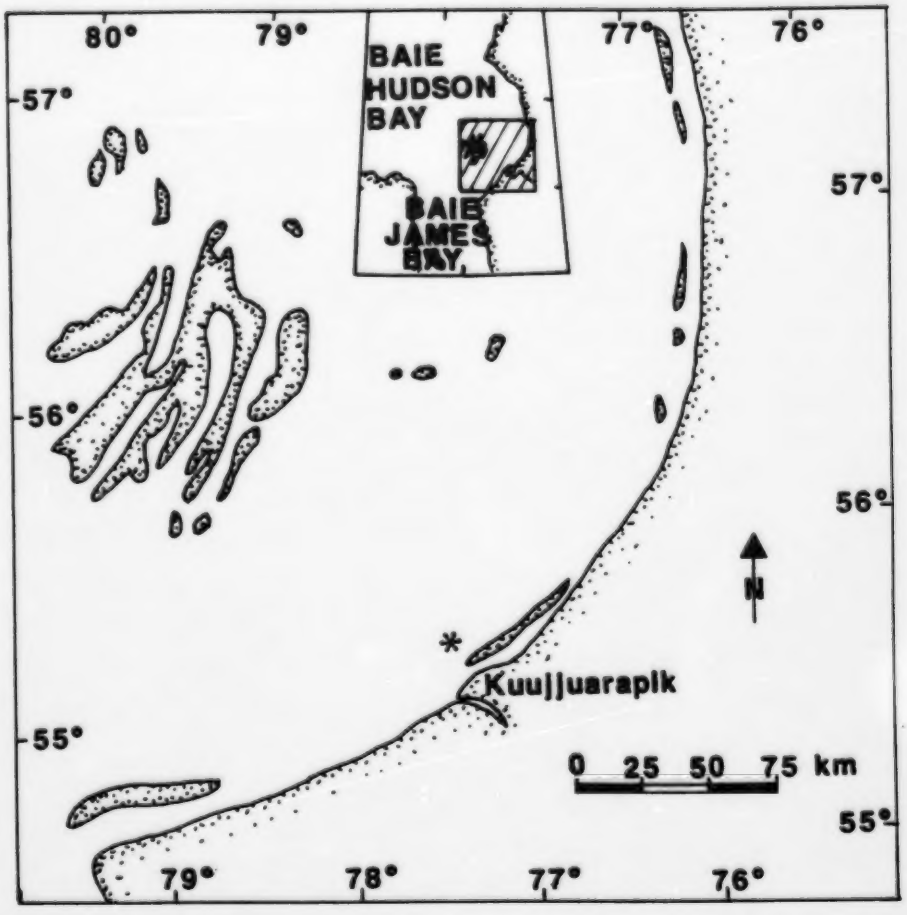

Figure 1. Experiment location in southeastern Hudson Bay with the mooring site indicated by an asterisk.

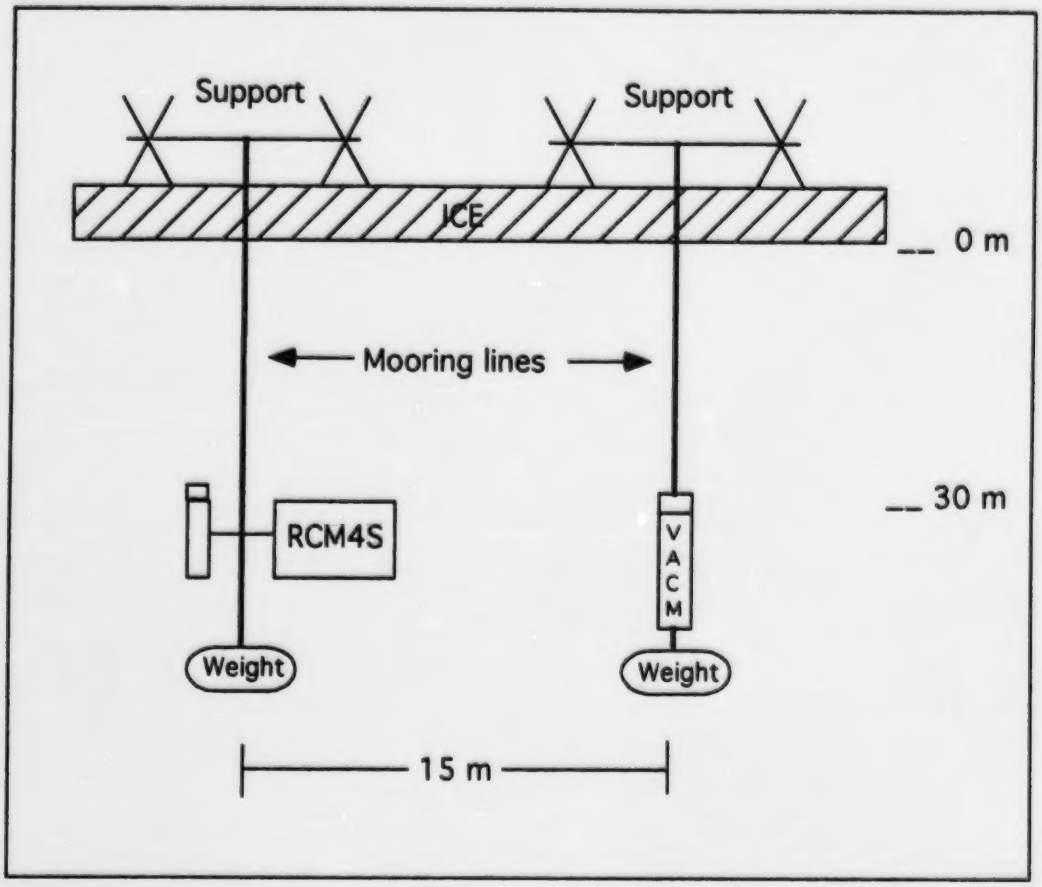

Figure 2. Under-ice mooring configuration.

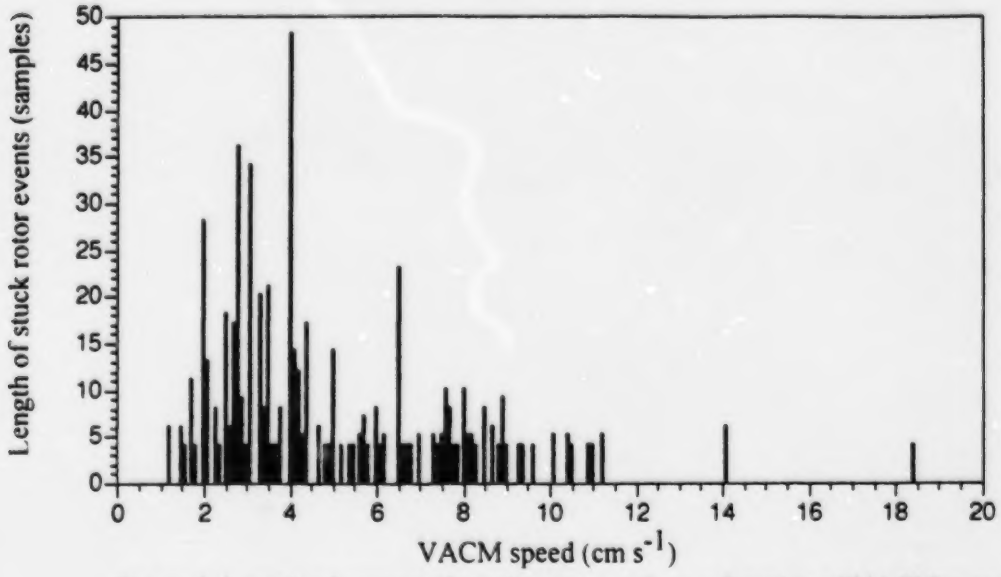

Figure 3. Length of suspected stuck rotor events as a function of VACM speed.

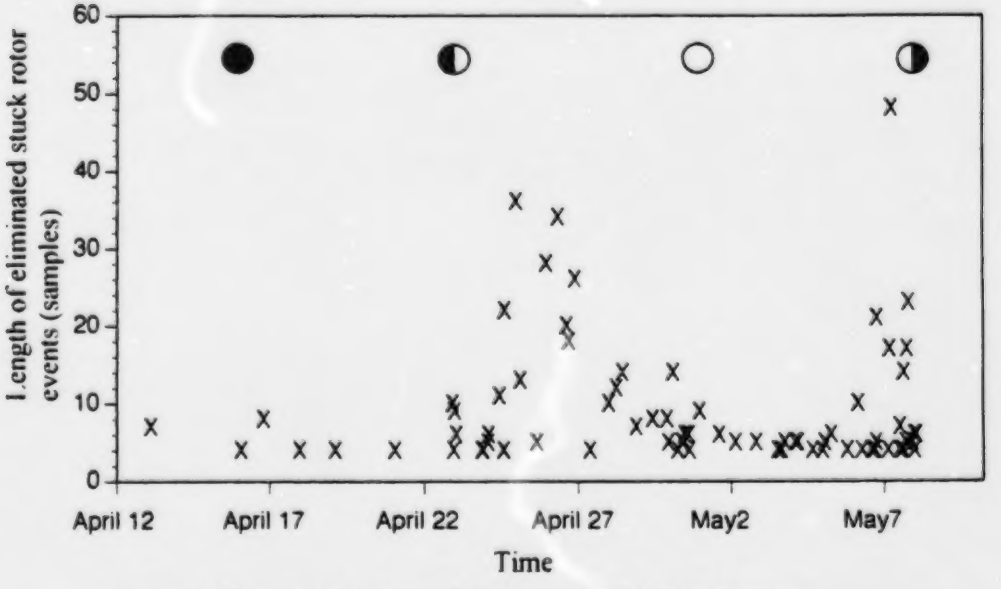

Figure 4. Time distribution of eliminated stuck rotor events.
Lunar phases shown.

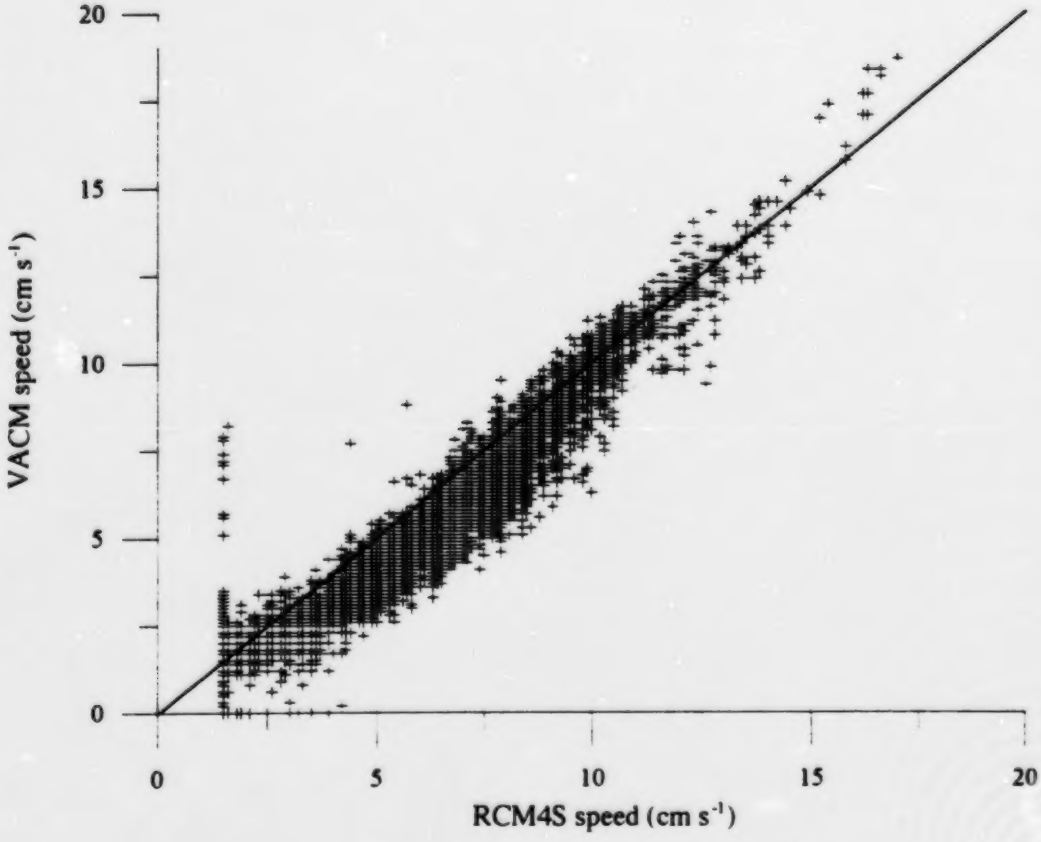

Figure 5a. Speed comparison between the two current meters. The straight line represents a 1:1 ratio.

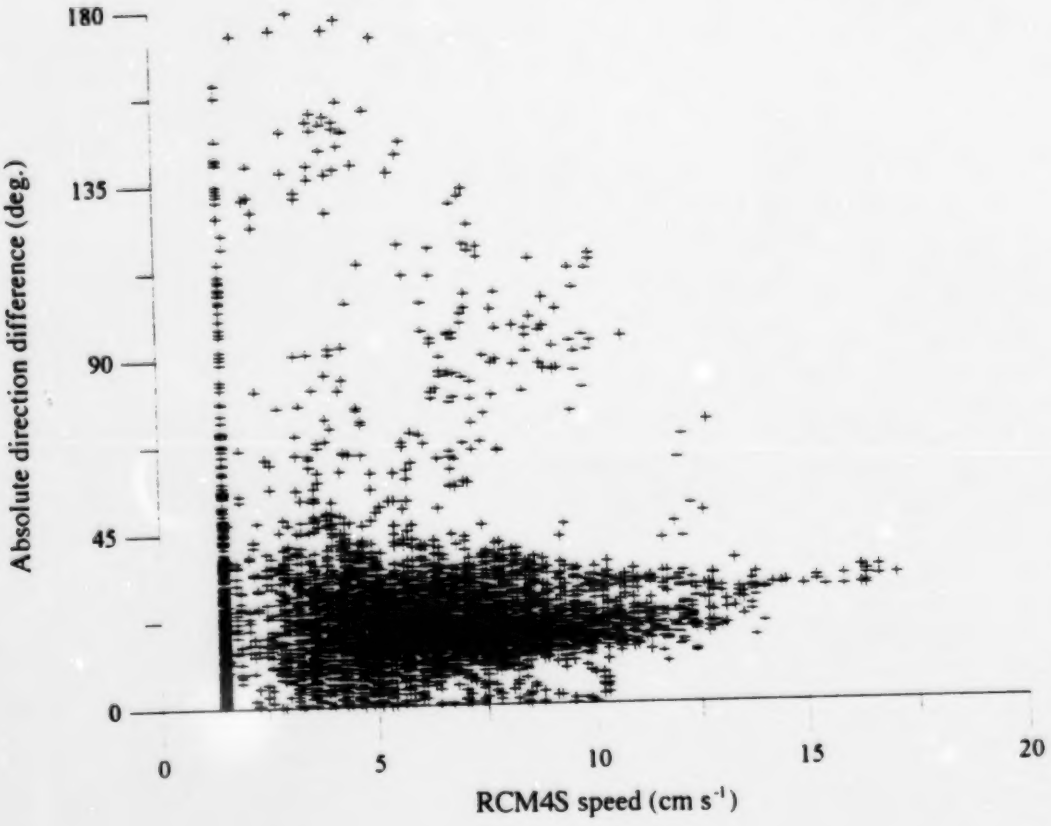

Figure 5b. Direction comparison between the two current meters.

APPENDIX 1

FORMULAS USED TO CONVERT RAW DATA INTO ENGINEERING UNITS

RCM4S:

Speed (cm s^{-1}) = $1.5 + (0.7 * RC / SI) * N6$

Direction (°True) = $1.5 + 0.349 * N5 + MD$

VACM12:

Speed (cm s^{-1}) = $2.4592 * N6 / 16$ if $0 \leq N6 \leq 16$

$1 + 0.0912 * N6$ if $17 \leq N6 \leq 199$

$3.5 + 0.0787 * N6$ if $200 \leq N6 \leq 4032$

Direction (°True) = $1.40623 * N5 + MD + C$

Where :

RC = number of rotor revolutions per count (fixed at 1)

SI = sampling interval (300 s)

MD = magnetic declination (-20°)

C = calibration correction (11.26°)

N5 = raw direction value from the tape

N6 = raw speed value from the tape